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UNSTABLE RESONATOR SEMICONDUCTOR LASERS

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14. ABSTRACT
We describe high-brightness, broad-area mid-IR semiconductor lasers. The optically pumped devices achieved higher brightness operation as unstable resonators. Each unstable resonator was realized by polishing or etching a diverging cylindrical mirror at one of the facets. In general, for facet separation L and diverging facet mirror radius R, the geometry generates two virtual mode source points located at distances V = +/- sqrt(L**2 + LR) from the flat facet. Radiation from a virtual source point is characterized by reimaging onto itself after a round trip through the resonator. If we refer to the figure, the left virtual source, *V(+)*, is at an object distance (V+L) from the diverging mirror with focal length (-R/2). Upon reflection from the curved facet, the radiation forms a virtual image, *V(-)*, at a distance (V-L) to the right of the curved facet. These distances satisfy the imaging equation

$$\frac{1}{V+L}-\frac{1}{V-L}=-\frac{2}{R}.$$

This regenerative reimaging of the circulating radiation is the critical mechanism leading to high brightness from the virtual source locations. In actual operation, we outcouple the radiation from the flat facet side of the device, so that the virtual waist of the lateral mode is located behind the output facet at a refractively reduced distance, D = V/n, in which the index of refraction is given by n=3.82. For a typical device geometry with L = 2500 mm and R = 10000 mm, this reduced distance is inside the device at approximately 1460 mm from the flat facet. In addition to the high brightness generated by the regenerative reimaging of the virtual source points, the natural divergence of the propagating mode tends to mitigate self-focusing filamentation, leading to further brightness improvements.
For several mid-IR unstable resonator devices, we will show experimental near- and far-fields near threshold, as well as at many times threshold. For these devices, the far-field is realized by reimaging the high-brightness virtual source point located a distance D from the flat facet.

15. SUBJECT TERMS
Optically pumped semiconductor lasers, antimonides, W lasers, mid-IR semiconductor lasers, unstable resonators

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Opening intro chart

SLIDES ONLY
NO SCRIPT PROVIDED

Outline

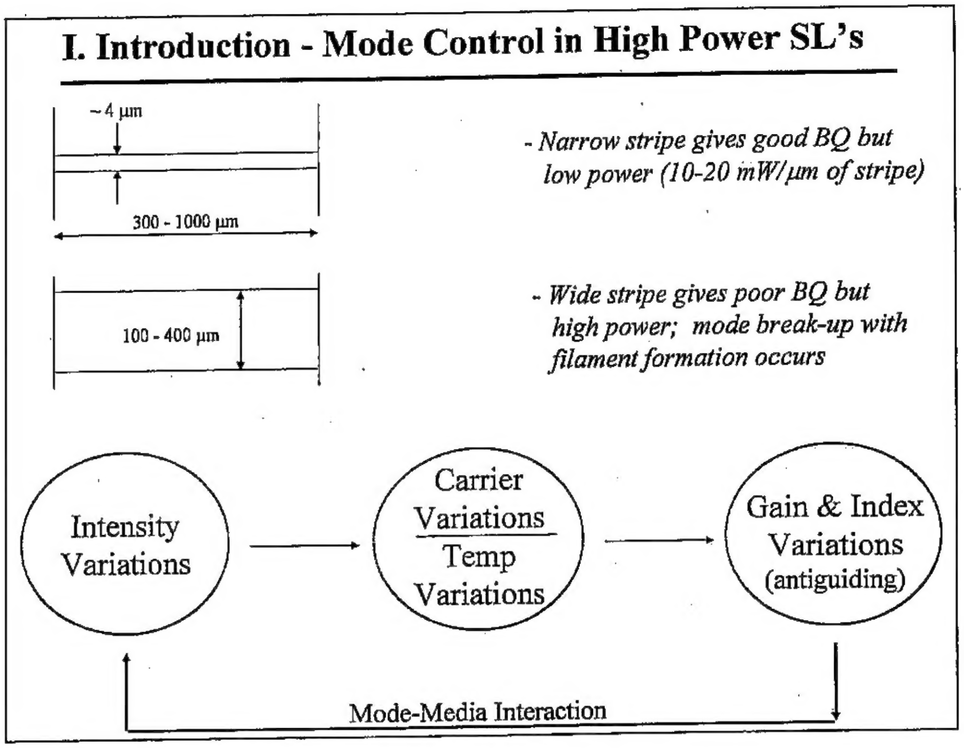
I. Introduction
- Mode Control in High-Power Semiconductor Lasers
- Mode-Media Interactions (Filament Formation)

II. Suppressing Filaments

III. Unstable Resonators for semiconductor lasers.

IV. Summary & Outlook

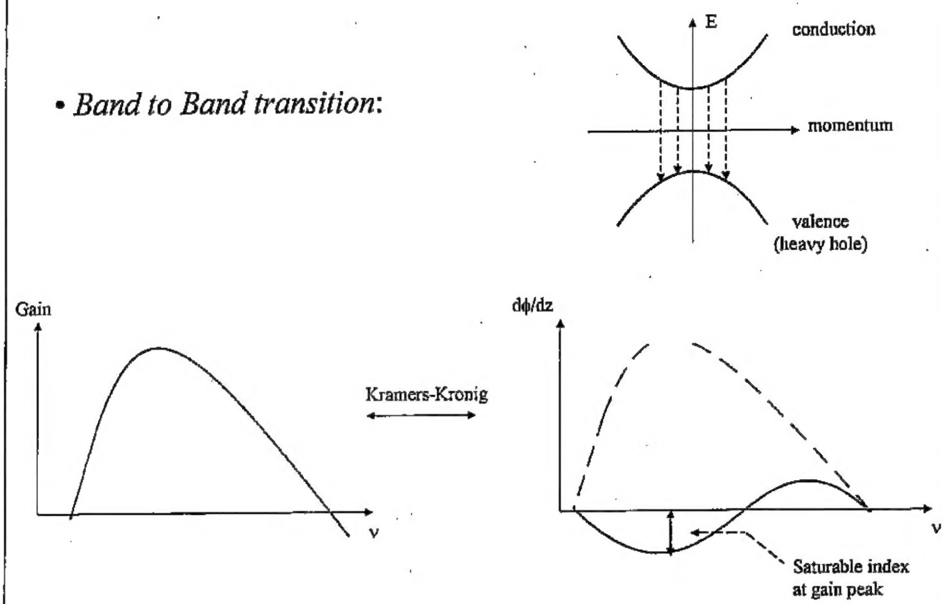
We will read the chart, we will offer some of the history of filament formation.



This chart describes the mechanisms of mode-media interaction in broad-area semiconductor lasers.

Gain / Index in Semiconductor Lasers

• *Band to Band transition*:

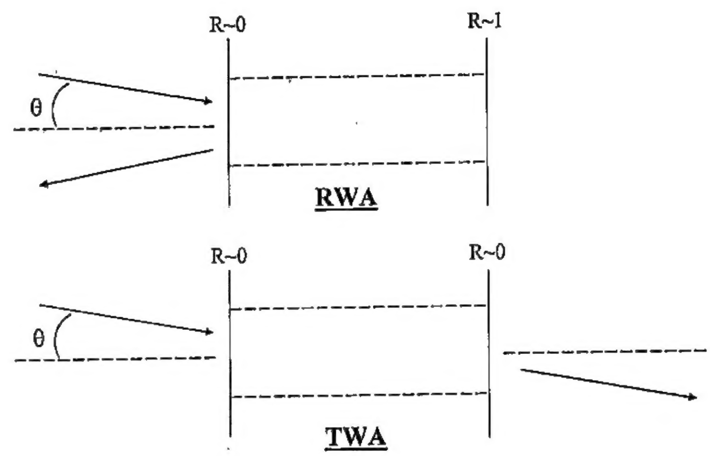


• *Saturable index at gain peak creates self-focusing*

This chart shows the asymmetric gain versus frequency curve for a typical band–to–band transition. This asymmetry leads to saturable index of refraction at the gain peak, the origin of self-focusing.

II. The Tilted Amplifier Solution

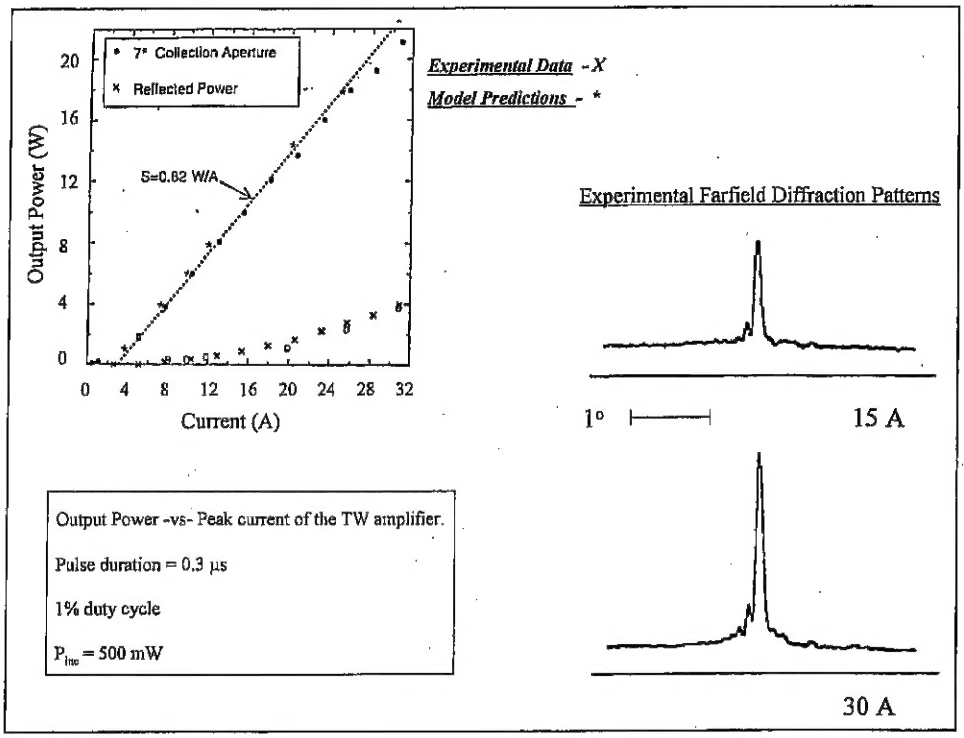
- *Several research groups have observed that tilted amplifiers can provide high-gain as well as good BQ:*



We will discuss the experiments on tilted semiconductor amplifiers that were done between 1990 -1995.

600 μm x 1500 μm Amplifier Results
7° angle of incidence (air)

This chart shows the configuration for a TWA, that provided 21 Watts of diffraction limited output power in a 1992 experiment.



These are the published results from that experiment.

Beam Propagation Method

Paraxial wave equation in the diode with filamentation tendencies given by α-parameter

$$\frac{1}{2ik}\frac{\partial^2 U}{\partial x^2}+\frac{\partial U}{\partial z}=\frac{\Gamma G(N(x,z))}{2}\cdot(1-i\alpha)\cdot U$$

$$(\alpha - \text{linewidth enhancement factor})$$

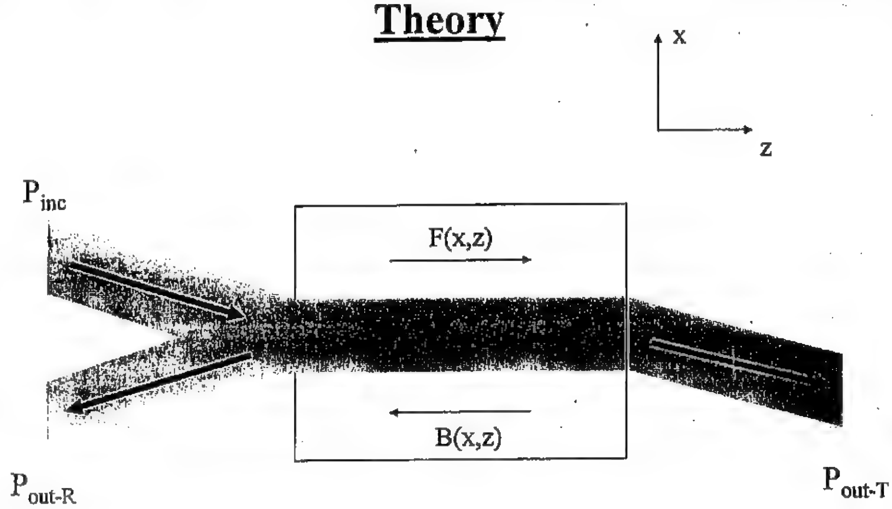
$$U(x,z)=F(x,z) \quad or \quad B(x,z)$$

Carrier diffusion in the diode

$$D_e\frac{\partial^2 N}{\partial x^2}-\frac{N}{\tau_s}-\frac{G}{h\nu}\cdot(I_f+I_b)+\frac{\eta J}{qW_a}=0$$

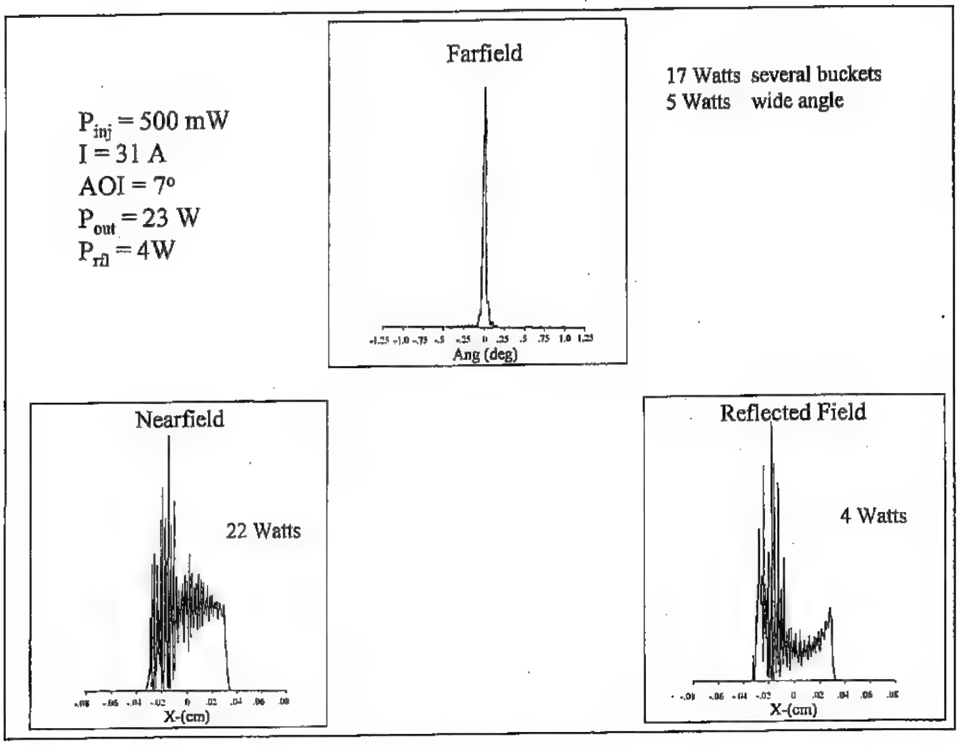
Wave optics modeling of semiconductor lasers or amplifiers requires simultaneous self-consistent solutions of the wave equation and the carrier diffusion equation.

Theory

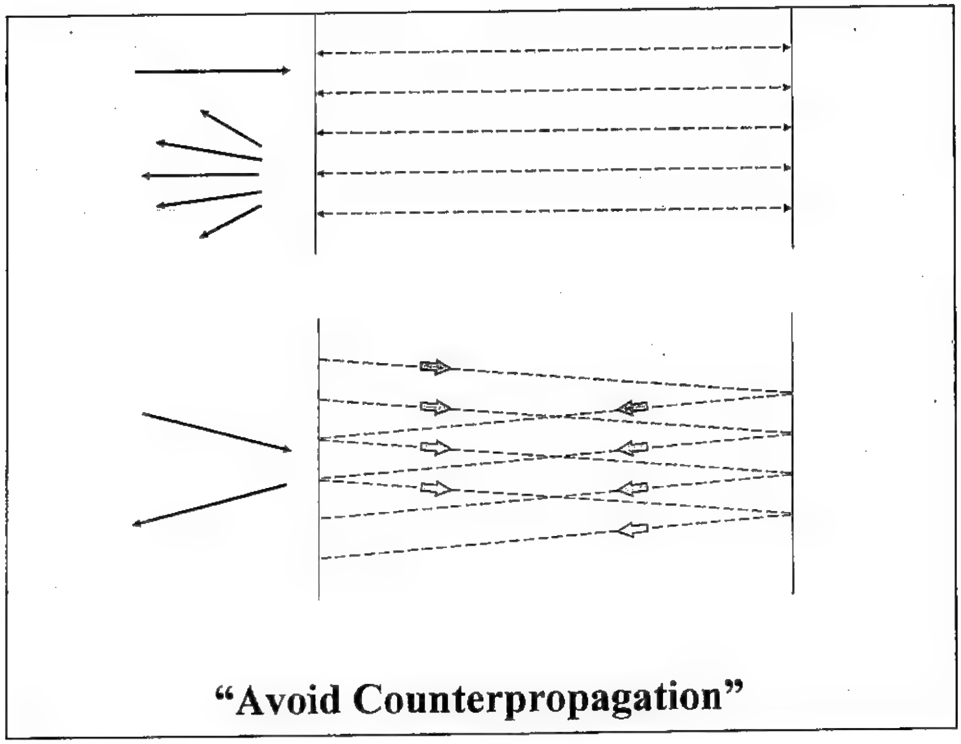


Must self-consistently determine F(x,z) and B(x,z)

This figure shows our modeling geometry.

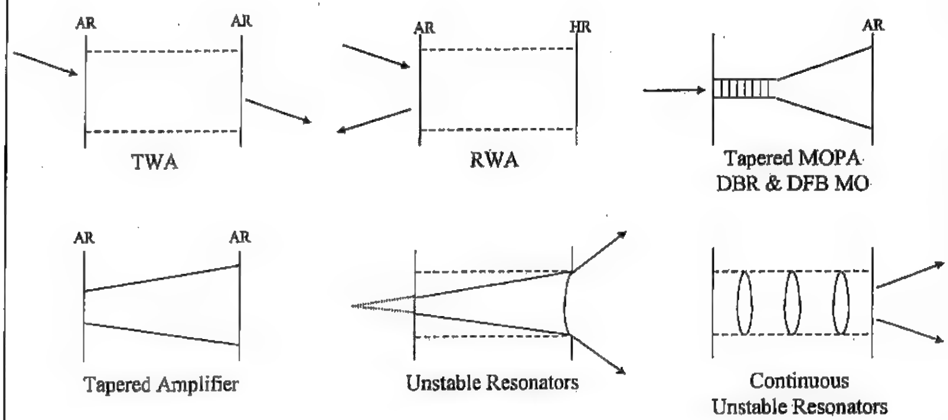


These are our simulation results, showing excellent agreement with the 1992 experiment.



This chart illuminates the substantial benefits realized by angled extraction.

Ways to avoid counterpropagation and achieve <u>angled extraction without filamentation</u>

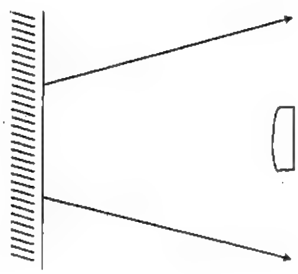


- *We will now concentrate on unstable resonators.*

All of these resonator configurations essentially avoid exact counterpropagation and offer promise for high power and good beam quality.

III. Unstable Resonators

• Invented by A. Siegman

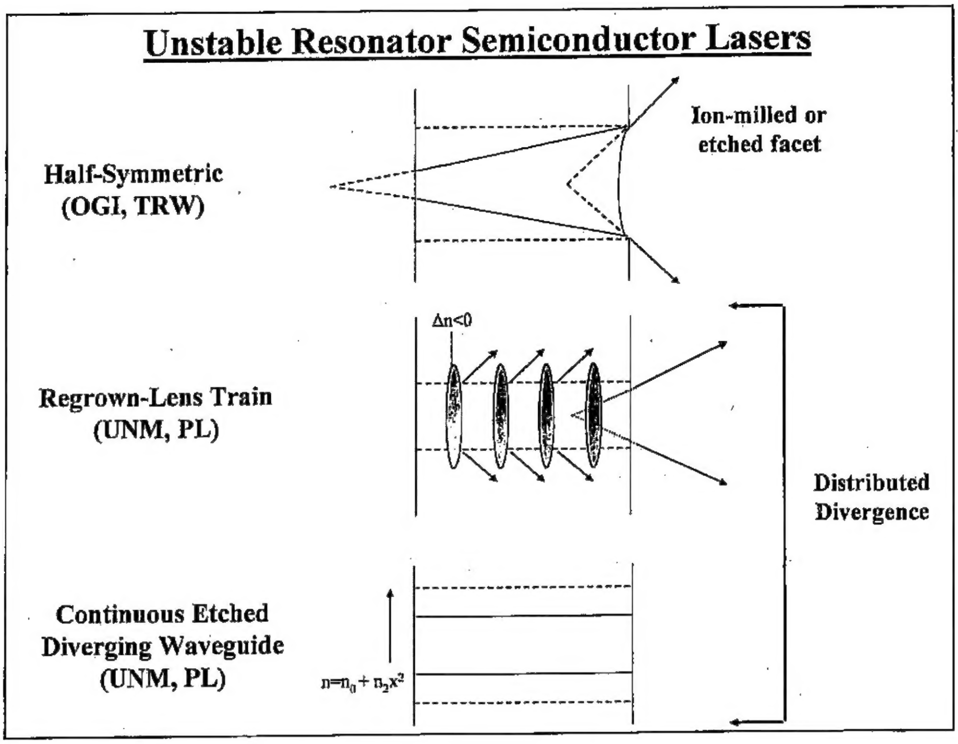


- Large mode volumes
- Near diffraction limited performance (good mode discrimination)
- Insensitive to misalignments and aberrations in the medium
- Avoids exact counterpropagation and suppresses filaments

• Applications to semiconductor lasers

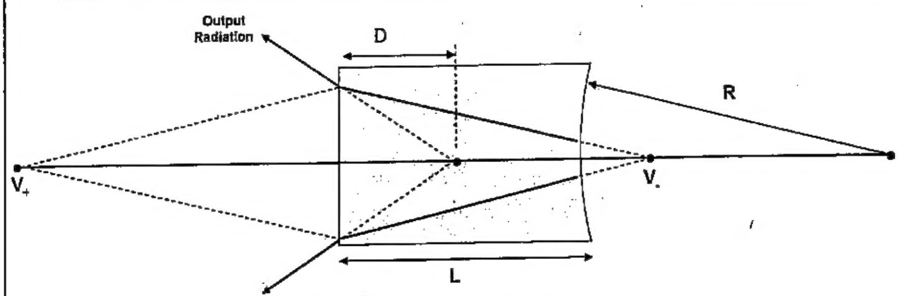
- Bogatov, et.al. (1980) - polished facet mirror
- Craig, PhD Disseration (1985) - etched facet mirrors
- Yariv, Salzman, et.al. (1985-87) - etched facet mirrors
- Tilton, Dente, et.al. (1989-present) - ion milled, etched, lens train

The unstable resonator has a long history and we will essentially cover that here.



These are the types of unstable resonators that have been implemented on semiconductor lasers.

High-Brightness from an Unstable Resonator Mid-IR Semiconductor Laser



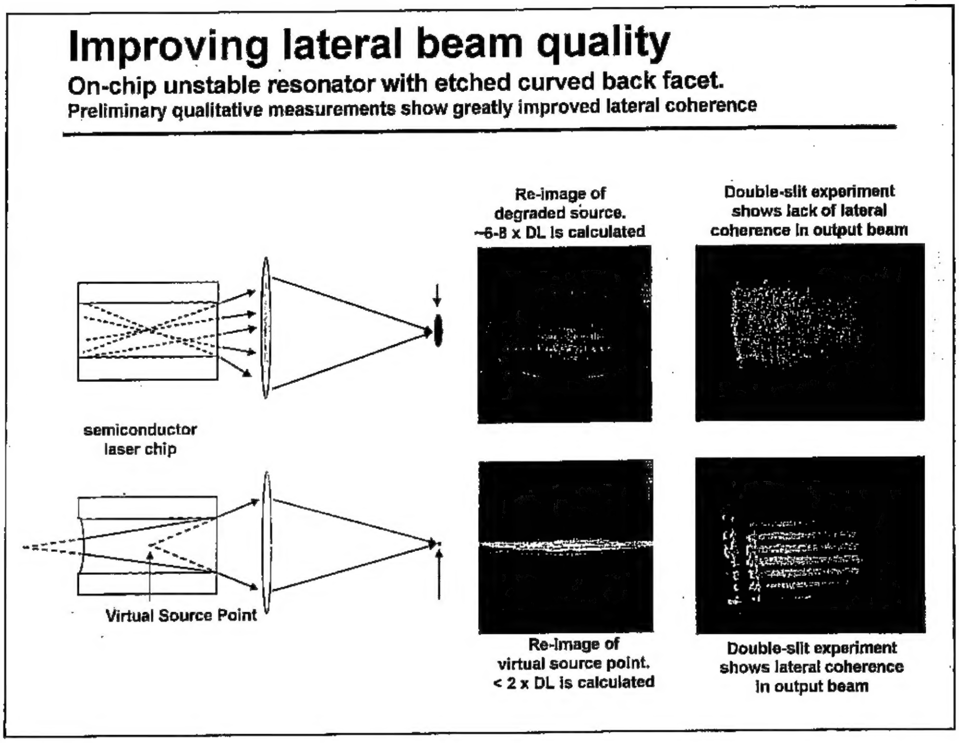
Schematic of unstable resonator showing virtual source points

- Two virtual mode source points located at distances $V = \pm\sqrt{L^2 + LR}$ from the flat facet; L = 3.4 mm, R = 7.5 mm, V/n = 1.6 mm.
- The left virtual source, V_+, is at an object distance (V+L) from the diverging mirror with focal length (-R/2). Upon reflection from the curved facet, the radiation forms a virtual image, V_-, at a distance (V-L) to the right of the curved facet. These distances satisfy the imaging equation:

$$\frac{1}{V+L} - \frac{1}{V-L} = -\frac{2}{R}$$

This chart illustrates the unstable resonator that we used in our recent experiment on optically pumped mid-ir semiconductor lasers.

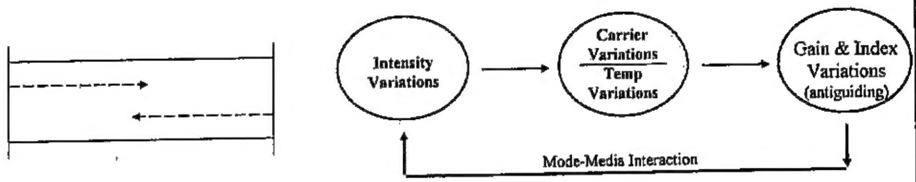
We will read through this chart.



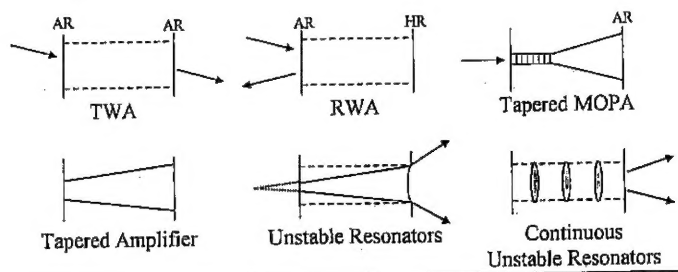
This chart shows the farfields of both a Fabry-Perot resonator and our unstable resonator. The right hand pictures show farfield interference when a double slit is inserted into the near field.

IV. Conclusions

- ***Filament formation problems have precluded high-power, good BQ, operation of broad-area semiconductor laser devices.***



- *Off-axis extraction, with angled counter-propagating fields, is an excellent way to ameliorate the filamentation tendencies.*



This final chart reviews the essential physics of mode-media interaction and filament formation, in addition it recalls the basic methods for obtaining high power and suppressing filaments.